Nationaal Lucht- en Ruimtevaartlaboratorium

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Flight tests to investigate supercooled large droplets in icing conditions

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ABSTRACT
NLR investigated the icing atmosphere for aircraft by flying with an instrumented research aircraft through clouds. Liquid water content, droplet diameter distributions and air temperature were measured. Large droplets were found in air masses with a limited extent. The flight campaign and the results from the campaign are presented. Measurements are compared with limits in regulations for aircraft and helicopter operation in icing conditions. The investigation was made in the framework of a European co-operation in the EURICE project, partially funded by the Directorate General VII for Transport of the European Commission.

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Abstract

NLR investigated the icing atmosphere for aircraft by flying with an instrumented research aircraft through clouds. Liquid water content, droplet diameter distributions and air temperature were measured. Large droplets were found in air masses with a limited extent. The flight campaign and the results from the campaign are presented. Measurements are compared with limits in regulations for aircraft and helicopter operation in icing conditions. The investigation was made in the framework of a European co-operation in the EURICE project, partially funded by the Directorate General VII for Transport of the European Commission.

Abbreviations

CIRA	Centro Italiano Ricerche Aerospaziali
DADC	Digital Air Data Computer
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EURICE	European Research on Aircraft Ice Certification
FAR	Federal Aviation Regulation
FSSP	Forward Scattering Spectrometer Probe
GKSS	Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt
GPS	Global Positioning System
INTA	Instituto Nacional de Técnica Aeroespacial
IRS	Inertial Reference System
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LWC	Liquid Water Content
MED	Mean Effective drop Diameter
MVD	Median Volume Diameter
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium NLR
NM	Nautical Mile
OAP	Optical Array Probe
PDPA	Phase Doppler Particle Analyzer
PMS	Particle Measuring Systems Inc.
SLD	Supercooled Large Droplets
TAT	Total Air Temperature
UK Met Office	Meteorological Office - Ministry of Defence (United Kingdom)

Contents

(15 pages in total)

1 Introduction

Supercooled large droplets have a lot of attention in the aviation community. Ice accretion on aircraft caused by SLD is different from ice accretion due to small droplets. Large droplets impinge on a larger chordwise range on a wing, which implies that a larger part of the wing has to be protected for ice accretion.

Current regulation covers a limited range for the droplet size distribution and liquid water contents. The regulation is based on measurements in the icing atmosphere performed some forty years ago. The validity of the description of the icing atmosphere is under discussion, which was induced by aircraft accidents and incidents in icing conditions (e.g. ref. 1). The certification requirements for aircraft operation in icing conditions are described in JAR/FAR chapter 25 and 29 (ref. 2). The atmosphere in which aircraft icing occurs is characterised in the Appendix C of the document.

Twelve partners co-operated in the EURICE project to investigate the aircraft icing certification and the operation of aircraft in icing conditions (ref. 3). One of the objectives of the project was to increase the knowledge of atmospheric icing conditions, where special interest was for SLD. The atmosphere with SLD was to be characterised in order to learn about the formation process of SLD. For this purpose three aircraft, of DLR, INTA and NLR, were flown to measure atmospheric conditions. This paper describes the NLR flight campaign and the results of the campaign. A comparison between measurements and the Appendix C description is presented.

2 The research aircraft and instrumentation

The NLR research aircraft for the EURICE flight campaign was a Fairchild Metro II (see fig. 1). Cloud physics instrumentation was added to the instrumentation of the aircraft for this project (see fig. 2). In clouds the droplet size distribution, droplet density, liquid water content and air temperature were the important parameters to measure. Standard aircraft instrumentation was operated to document wind parameters and the position of the aircraft. In table 1 the instrumentation relevant for EURICE is listed. The instruments are described to illustrate how parameters were measured during the campaign. Some of the parameters were measured with different instruments. These were compared and results are mentioned.

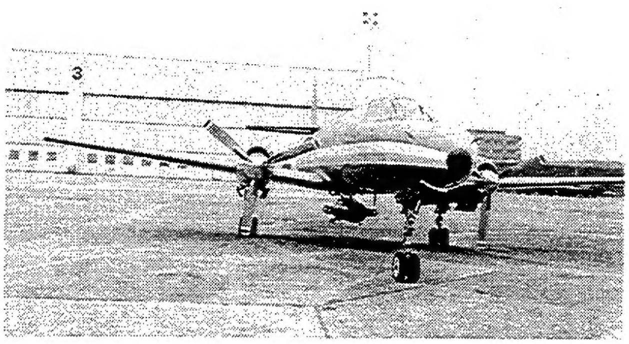

Fig. 1 The NLR Fairchild Metro II in the EURICE configuration. The cloud physics instrumentation for measuring droplet size distribution, droplet density and liquid water content was installed on a pod mounted under the fuselage.

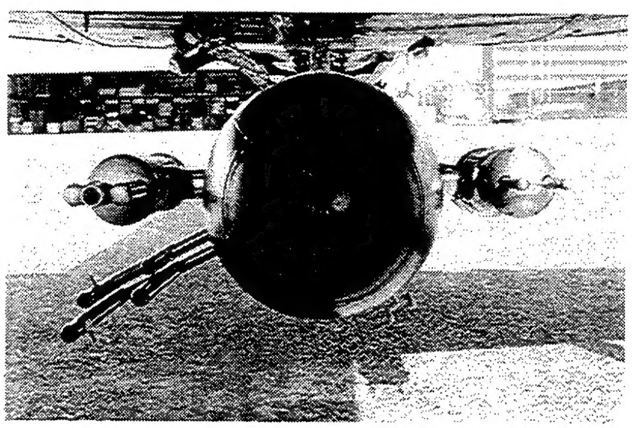

Fig. 2 The pod with cloud physics instrumentation installed under the NLR research aircraft

Table 1 Aircraft instrumentation relevant for the investigation

Instrument	Make	Type
Csiro King	PMS	KCLWC-5
FSSP	PMS	FSSP 100
OAP	PMS	OAP 2DC
PDPA	Aerometrics	ADA 100
DADC	Honeywell	4045053
TAT probe	Rosemount	102 W2W
IRS	Honeywell	HG 1050
GPS receiver	Trimble	TNL 2000

2.1 Csiro King

The Csiro King is an instrument measuring the liquid water content in the atmosphere. The heat necessary for maintaining a temperature of a rod exposed to the atmosphere is measured. The liquid water content in the atmosphere is derived from the extra heat necessary for heating and evaporating liquid water. The heat necessary to keep the temperature in dry air, the so-called dry-term, is dependent on airspeed, air temperature and pressure. This dry term is to be determined in calibration runs for subtraction. The accuracy of the probe is 0.1 g/m^3. The Csiro King probe applied in the flight campaign was provided by the Max Planck Insitut für Meteorologie of the University of Hamburg.

2.2 FSSP and OAP

The FSSP and OAP measure the particle size distributions optically. The FSSP measures the light scattered by a particle and correlates the scattered light intensity to the size of the particle and the OAP images particles on a detector array. The FSSP and OAP together deliver the information about droplet size distributions in the atmosphere and the number density of droplets relevant for icing. However, the sensors are not able to distinguish between solid and liquid particles. OAP images can be processed such that non-spherical particles are omitted. In this way ice crystals with sizes of larger than about 150 micrometer are recognised quite reliably. For smaller particles the information is unreliable. The PDPA has better capabilities for distinguishing between droplets and crystals.

The water content can be calculated from particle size distributions and number densities. The uncertainty in these calculations is large. A major uncertainty is in the sizes of the measurement volumes of the instruments. Considerable uncertainties for water content measurements have been reported in literature (ref. 4, 5). The FSSP and OAP probes applied in the campaign were

provided by the German institute GKSS. LWC data of the Csiro King and water content data derived from FSSP and OAP measurements were compared. Differences of up to a factor of 4 between integrated FSSP and OAP data and Csiro King were found. The FSSP and OAP are preferably not applied for determining LWC.

2.3 PDPA

The PDPA measures the size distribution of particles, the density of particles and the velocity of particles with light scattering techniques. The PDPA distinguishes between ice crystals and droplets. The PDPA is a new and potentially better instrument than the FSSP and OAP combination. It is developed by Aerometrics Inc. (ref. 6), who supported the operation during the flight campaign. The PDPA flown during these flights is owned and was operated by CIRA.

2.4 IRS, DADC, GPS and TAT probe

The IRS is a system with three Ring Laser Gyro's, three servo accelerometers and signal processing electronics. This type of IRS is also installed in the larger commercial aeroplanes for accurate navigation during several hours. The system measured the motion and the attitude of the research aircraft. The Digital Air Data Computer provided pressure altitude and airspeed during the flights. DADC data combined with IRS data provide an indication for windshear and turbulence in the atmosphere. The GPS receiver provided information about the position of the aircraft. The TAT probe was selected because the water shedding characteristics of the probe are good. This is an important feature for gathering accurate temperature measurements in clouds.

3 Flight campaign overview

The campaign was flown in a 5-week period in March and April 1997. Data were gathered in 5 measurement flights. In all measurement flights icing conditions were encountered. In two of the flights the ice accretion on the aircraft was such that pilots decided to abandon the icing conditions to lower altitudes with temperatures above zero degrees Celsius.

3.1 Cloud description

In the operational plan for the flight campaign it was recognised that most information about icing conditions can be derived from icing conditions in stratiform clouds. However, finding icing conditions in flight is not easy and the choice for the conditions is very limited especially if the operational period is limited as in this flight campaign. In the first measurement flight on 16 March 1997 the clouds in a frontal system showed little convective activity and these clouds are close to ideal for the investigations. Some convective transport was encountered in the second and third flight and considerable convection was in clouds investigated in the fourth and fifth flight. The clouds investigated during the first flight were stable and can be characterised as stratiform. The clouds investigated in the other flights had a cumuliform character.

3.2 Weather forecasts

Icing forecasts were obtained from the UK Met Office as well as from the local Royal Netherlands Meteorological Institute KNMI. Detailed weather information and short term forecasts appeared to be vital for the planning of the flight test campaign.

The forecast for icing provided by the local weather office included a moderate to severe icing forecast for each of the measurement days. Ice accretion on the aircraft was encountered in all flights, but with various rates.

4 Supercooled large droplets and the Appendix C

In fig. 3 the Water Content and MVD derived from FSSP and OAP data are plotted for the measurement flight on 16 March 1997. The MVD in the droplet distribution is defined as the diameter for which 50 % of the Water Content is in droplets smaller than the MVD. Water Content and MVD are averaged for 1 second time intervals. The periods in which the MVD is larger than 50 micrometers are short. However, some of the periods are longer than the periods considered in the JAR/FAR 25/29 for certification of aircraft as will be shown below. The conditions should be considered as outside the limits described for aircraft certification.

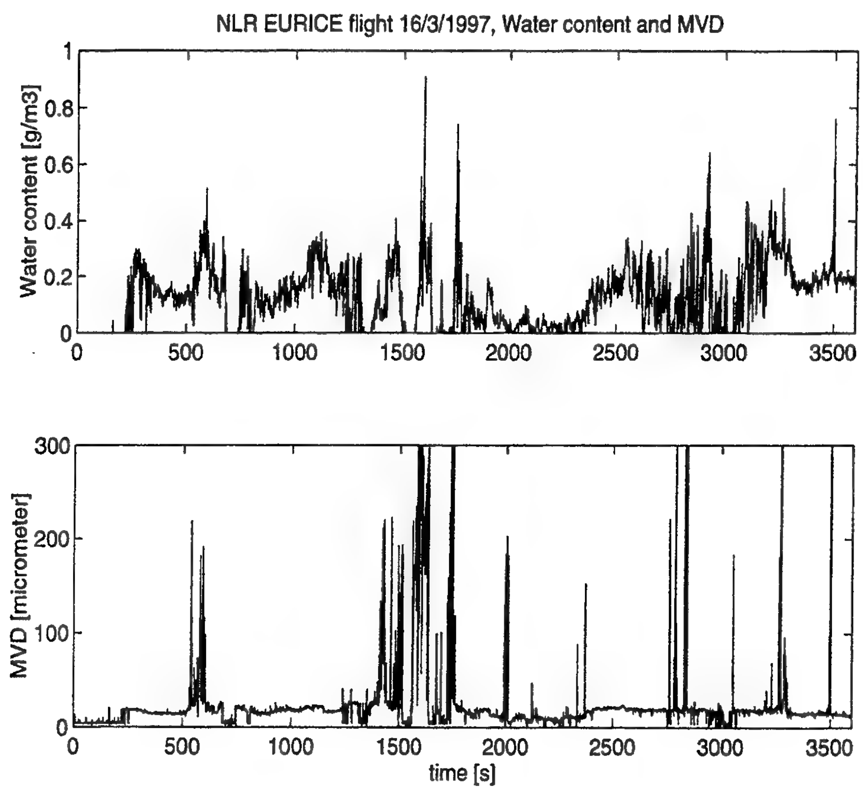

Fig. 3 The water content and the MVD time series derived from FSSP and OAP data.

4.1 Comparison of measurement results and Appendix C

In the Appendix C of JAR/FAR 25/29 the parameters LWC, MED, (static) air temperature and horizontal extent of the cloud are used as descriptors of the icing atmosphere. The MED is defined in icing conditions with assumed distributions of droplet diameters, whereas the MVD is defined for a measured droplet distribution. For this study the difference is of no relevance.

In the OAP images recorded on 16 March 1997 no ice crystals were observed, which implies that all water can be considered as liquid. The LWC values are not large compared with the limits in Appendix C. However, the MVD is larger than the 40 and 50 micrometer mentioned during some short periods.

Appendix C recognises the continuous cloud and the intermittent cloud limits, with horizontal extents of 17.4 NM and 2.6 NM. (see fig. 4). These horizontal extents correspond to around 350 s and 50 s time intervals for the airspeed flown on 16 March. Averages over these time intervals were calculated. Conditions with a MVD larger than 50 micrometer which have a horizontal extent longer than 2.6 NM are considered as SLD conditions outside of Appendix C. An example of such a condition is shown in fig. 5 where the extent was 10 NM, much longer than 2.6 NM. MVD was 214 micrometer, static temperature of air was -1^{0}C and the average LWC (derived from FSSP and OAP data) was 0.09 g/m^3 for the 10 NM flight segment.

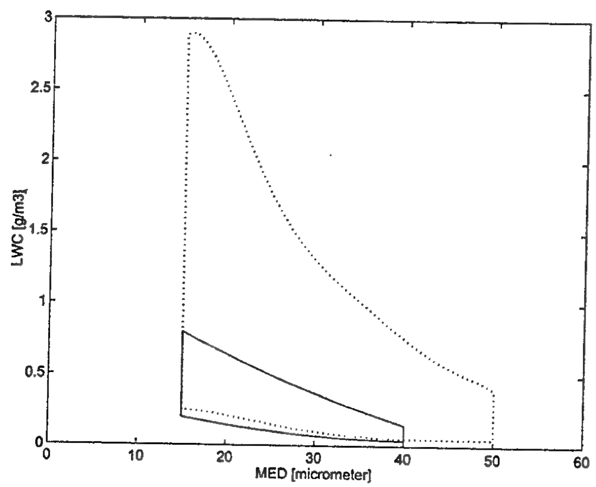

Fig. 4 Envelopes of MED and LWC ranges for the continuous cloud (-) and intermittent cloud (...) limits described in JAR/FAR 25/29 Appendix C icing conditions. Within these envelopes additional limits are set for temperature and altitude. The complete description is given in ref. 2

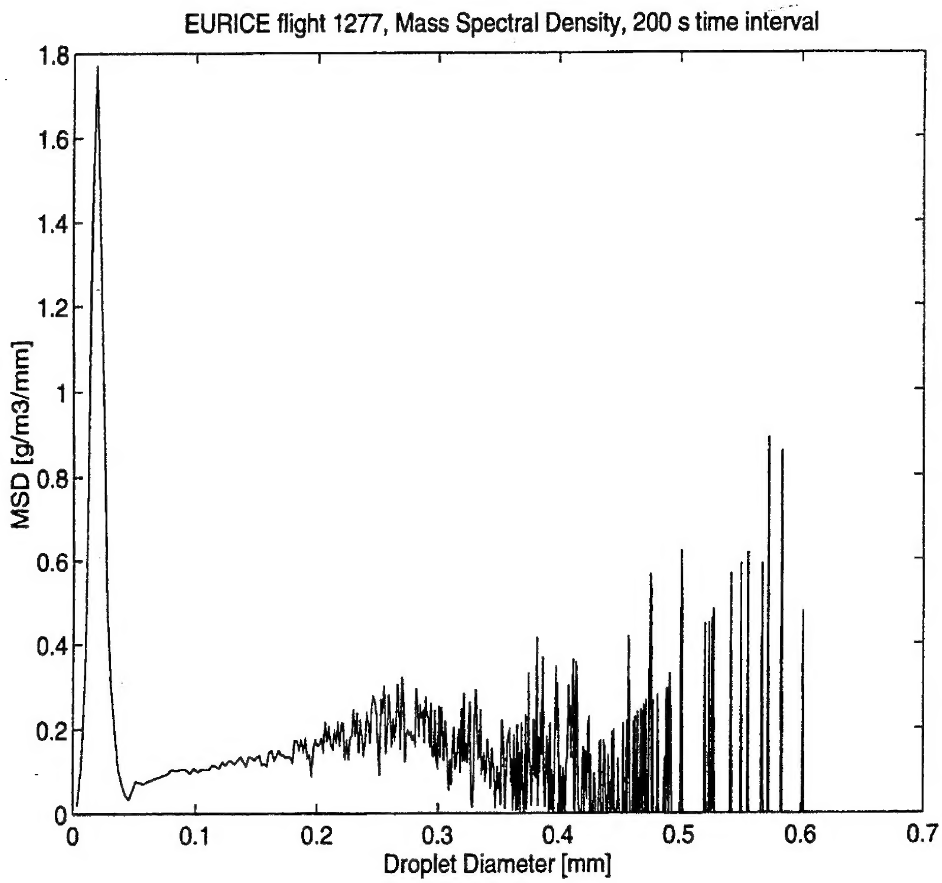

Fig. 5 Droplet mass density distribution for droplets measured in the flight on 16 March 1997 in a 200-second time interval. The maximum mass density is for droplets of 19 micrometer, the MVD is 214 micrometer.

Averaging over 350 seconds from 51350 to 51700 s, corresponding to 17.6 NM, leads to an average MVD of 52 micrometer at -2^{0}C and the average LWC (derived from FSSP and OAP data) was 0.11 g/m^3. This is above the 40 micrometer limit for continuous conditions and therefore not included in the JAR/FAR 25/29.

SLD were also found in other flights. In the other flights the number of ice crystals was also considerable. These should be eliminated for determining the MVD of supercooled droplets and the LWC. Software for doing so automatically was not available for this project and classifying the images by eye is very subjective. Therefore, the quantitative values of MVD of droplets and LWC are presented for the flight on 16 March only.

4.2 Wind parameters

Correlations between the occurrence of SLD conditions and wind parameters such as windshear, the vertical wind component or turbulence parameters were investigated by analysing the data of the IRS and DADC together with MVD and LWC data. Correlations would provide useful information for research into the creation process of SLD or icing. However, no significant correlations were found in the data.

5 Conclusions

SLD were found in the atmosphere during short periods, corresponding to a few nautical mile horizontal extent. For some periods the extent and the MVD were such that the conditions should be considered as outside the Appendix C envelope defined for aircraft certification.

Several SLD conditions were found in the limited number of flights possible for this investigation, which indicates that short SLD conditions may be encountered quite frequently in aircraft operations. The frequency of encounters seems in contradiction with the omission of SLD conditions in the certification requirements for aircraft in icing conditions and the related regulation for aircraft operations. SLD conditions were also observed in other flight campaigns (ref. 7). Competent bodies should consider modification of certification requirements and regulation. The measurement results have been distributed amongst others to JAA. Investigations have been initiated (ref. 8).

A correlation between occurrence of SLD and wind parameters such as turbulence and windshear was not found.

Measurement results show uncertainties and disagreements for some parameters. Improvement of the instrumentation for in-flight cloud physics measurements seems necessary for retrieving accurate results. Nevertheless, the flight campaign produced valuable information about icing conditions in relatively few flights. Appropriate attention for the planning of flights contributed to this.

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